

THE HYDRAULICS OF GRAVITY-FLOW  
WATER WELLS

BY

DAVID HUME CALDWELL

B. S., University of California, 1938

M. S., University of Illinois, 1940

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIRE-  
MENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY  
IN ENGINEERING IN THE GRADUATE SCHOOL OF  
THE UNIVERSITY OF ILLINOIS, 1942

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## THE HYDRAULICS OF GRAVITY-FLOW WATER WELLS

The purpose of this thesis was to make a thorough mathematical analysis of the hydraulics of gravity-flow water wells. During the investigation it was found that rigid mathematical analysis of some aspects of the problem was impossible and in those cases the results of tests on actual flow models were used to obtain semi-empirical solutions.

The literature relating to the movement of underground water especially applicable to gravity-flow phenomena has been reviewed and a bibliography with short abstracts of each article is presented.

The significance of the coefficient of permeability in Darcy's law is discussed and the various methods for the measurement thereof have been classified as laboratory, indirect and field methods. Each method of measurement is reviewed briefly.

The range of validity of Darcy's law is discussed and it is concluded from the results of the most precise tests available that there is no "minimum hydraulic gradient." The upper limiting velocity where Darcy's law may be expected to fail is given by a Reynolds number of 1.

A gravity well is characterized by uniform atmospheric pressure over the surface of the water in the sand adjacent to the well. The existing equations of flow from a single gravity well are discussed and from experiments on electric models and on a sand model it is concluded that the Dupuit equation

$$Q = \frac{\pi k (h_e^2 - h_w^2)}{2.3 \log r_e / r_w}$$

where  $Q$  = discharge from well—cubic feet per second

$k$  = coefficient of permeability—feet per second

$r_e$  = distance from the well center to the boundary of the area of influence where the depth of water referred to the bottom of the well is  $h_e$  — feet

$r_w$  = radius of the well, feet

$h_w$  = depth of water in the well while pumping—feet.

can be used in computing the flow from a gravity well for all values of  $h_e - h_w$  and that the maximum flow from the well would occur when  $h_w = 0$ .

It is shown that the Dupuit equation cannot be used to define the free surface of the water in the sand adjacent to the well. As the result of experimental analysis the following equation giving the free surface has been developed.

$$Q = \frac{\pi k (h_e - h_x) h_e}{2.3 C_x \log r_e / 0.1 h_e}$$

where  $h_x$  = height of free surface above the bottom of the well

$C_x$  = a constant

The effect on the discharge of a gravity well of such factors as sloping water table, non-circular area of influence, the well not in center of area of influence, vertical replenishment, and impervious boundaries to the water-bearing sand are discussed.

A theoretical analysis of the drawdown-recovery curve has been made and the equations developed are compared with the results of available tests reported in the literature. The equation relating time and quantity of flow from the well is given as follows:

$$T = \frac{0.184 r_e^2 f}{Q} (h_e - \sqrt{h_e^2 - 1.69 Q/k})$$

where  $T$  = time-hours

$f$  = specific yield of water-bearing medium

The drawdown corresponding to the discharge  $Q$  at any time  $T$  can be calculated from the Dupuit equation.

The general theory of the partial penetration of a water-bearing stratum by a single gravity well and a theory of interference effects in small groups of wells have been adapted from Muskat and presented in brief form. Tests of the interference effects of small groups of wells have been compared with the theoretical equations and, as a result, it has been concluded that the theoretical equations are valid.

## VITA

Born August 9, 1914, Lansing, Michigan.

Attended schools in San Diego, California.

Graduated with honors in 1938 from the University of California with B.S. degree in Civil Engineering, Sanitary Engineering option.

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## PUBLICATIONS

1. "Laminar Flow of Sludges in Pipes with Special Reference to Sewage Sludge," H. E. Babbitt and D. H. Caldwell, Bul. 319, Univ. of Illinois, Eng. Exp. Sta., 1939.
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